Comparison of WIPL-D to Other EM Computation Methods

R. W. McMillan and J. H. Kirkland
U.S. Army Space and Missile Defense Command
106 Wynn Drive, Huntsville, AL 35805, USA
bob.mcmillan@smdc.army.mil, pete.kirkland@smdc.army.mil

Abstract: The computation of radiation patterns of complex antennas and the determination of scattering patterns of complex structures requires the solution of Maxwell's equations in either the time or frequency domain. In almost all applications of interest, these equations cannot be solved in closed form, and numerical methods must be employed to effect solution. Of the techniques available, including the Finite Element Method, the Finite Difference, and the Finite Difference Time Domain approaches, the Method of Moments (MoM) surface integral equation solves Maxwell's equations for conducting structures more efficiently. The electromagnetic computation application WIPL-D (Wires, Plates, and Dielectrics) is a commercially available analysis tool based on the MoM. It has the advantage, compared to other tools of this type, of requiring fewer unknowns for accurate computation, thus reducing the computation time. The reduction in number of unknowns is based on the employment of knowledge-based polynomial basis functions that require only 10 to 20 unknowns per square wavelength, compared to 100 to 300 unknowns for other methods. Also, in addition, because of the use of entire domain basis functions, continuity of the charge is guaranteed. In this paper we discuss this difference and give examples of the speed and accuracy of WIPL-D in practical applications.

1. Background

The solutions of Maxell's equations give an exact representation of the electromagnetic fields generated by scattering of electromagnetic waves by complex objects and the radiation patterns of complex antenna structures. Unfortunately, Maxwell's equations, although elegant and exact, are not generally solvable in closed form for most practical cases of interest. This limitation, together with the availability of high-speed computers, has given rise to a number of excellent computational tools for the solution of Maxwell's equations for practical scenarios. In this paper we discuss the electromagnetic computation code WIPL-D and compare it in general to other methods of computation.

WIPL-D is based on the MoM techniques described by Harrington [1]. It treats all structures as being composed of appropriately interconnected wires, plates and dielectrics [2]. To effect solution of Maxwell's equations, the structure is first defined in terms of its geometric parameters. The distribution of currents and charges is then determined based on the solution of the electric field integral equation (EFIE) which is expressed in terms of the magnetic vector potential and the electric scalar potential. Calculations of currents along wires are effected by approximating the current by a finite polynomial sum, and calculations of currents over plates are achieved by using a finite double polynomial sum. WIPL-D does these calculations by using lower-order polynomials for portions of the structure that are not changing rapidly as a function

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of displacement, such as large expanses of a flat plate or a very long wire. The result is a reduction in computation time of up to a factor of 100 depending strongly on the geometry of the problem being solved. If the distribution of currents and charges is known, all other quantities of interest including the radiated or scattered field, the near field, the impedance of generators driving the structures, etc. can be determined. The next section gives some examples of the speed and accuracy of WIPL-D applied to some practical problems.

2. Examples

Consider the well-known problem of Mie scattering by a combined dielectric and a perfectly conducting sphere. This problem may be solved to any desired accuracy using Maxwell's equations [3]. In this analysis, we compare the solutions obtained for the θ and ϕ components of the scattered field for illumination in the θ plane using WIPL-D to those obtained using the EFIE, MFIE (magnetic field integral equation), and CFIE (combined field integral equation) using the conventional subsectional basis functions. WIPL-D uses EFIE with higher order basis functions. The results of calculating the scattered fields using these different methods are shown in Figure 1. Although a similar number of unknowns is used for all cases (2376 for CFIE versus 2304 for WIPL-D) this figure shows that the results of WIPL-D is not marred by the internal resonance problem even though it is using the EFIE. The results are comparable to that of the CFIE at half the cost. This illustrates that the use of higher order basis is not terribly affected by the internal resonance problem as the defect is confined to an extremely small region and unless one inputs the frequency accurate to several decimal places the results are quite good. This point is illustrated in details in the next example.

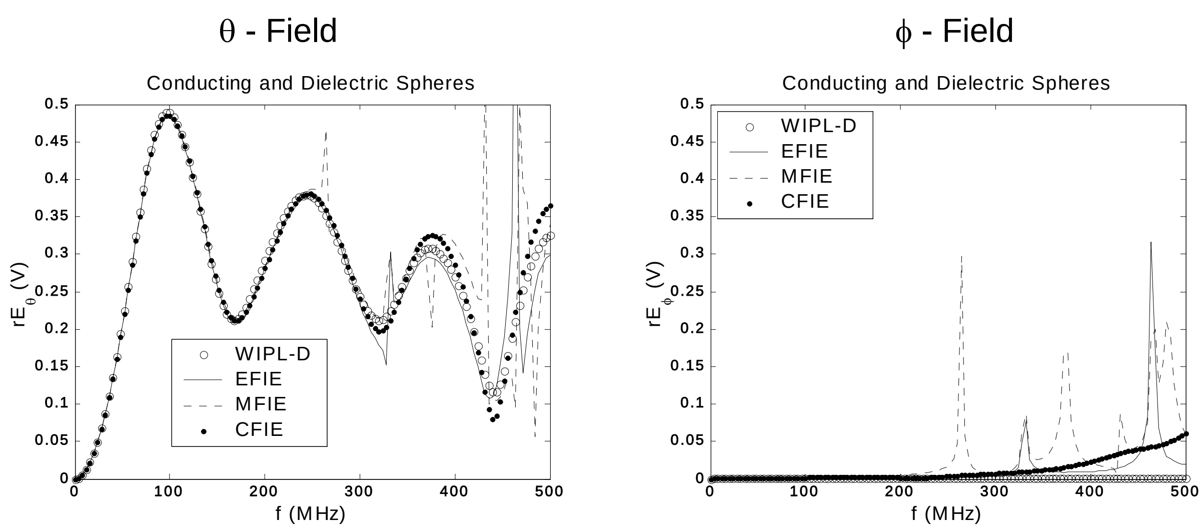


Figure 1. Comparison of results obtained with WIPL-D for calculation of scattering by conducting and dielectric spheres to those obtained by other methods. Note that use of a higher order basis in the expansion function is more forgiving to the internal resonance problem.

Another canonical shape of interest for radar cross section calculations is the cube. All known methods of computation of cube radar cross section exhibit artifacts caused by the nature of the numerical computation, but with WIPL-D these artifacts are essentially negligible except at the frequencies very near the internal resonant frequency. Figure 2 shows the monostatic RCS of a cube of side 2 m over the frequency range 100 – 110 MHz, which is the region in which the first internal resonance occurs. Curves A, B, and C were calculated using the piecewise constant and linear basis functions in which M is the number of patches and N is the number of unknowns. Curve D was plotted using WIPL-D with higher order basis functions and 24 patches, or 2 patches per cube face. Figure 2 shows that the use of the higher order basis has localized the defect of the EFIE in a very narrow region. Unless one puts in the value for the frequency with several significant digits the internal resonance problem is virtually nonexistent. This is in contrast to the subsectional basis where similar effects are observed when one increases the number of basis functions as seen in Figure C, as compared to Figure A of Fig. 2.

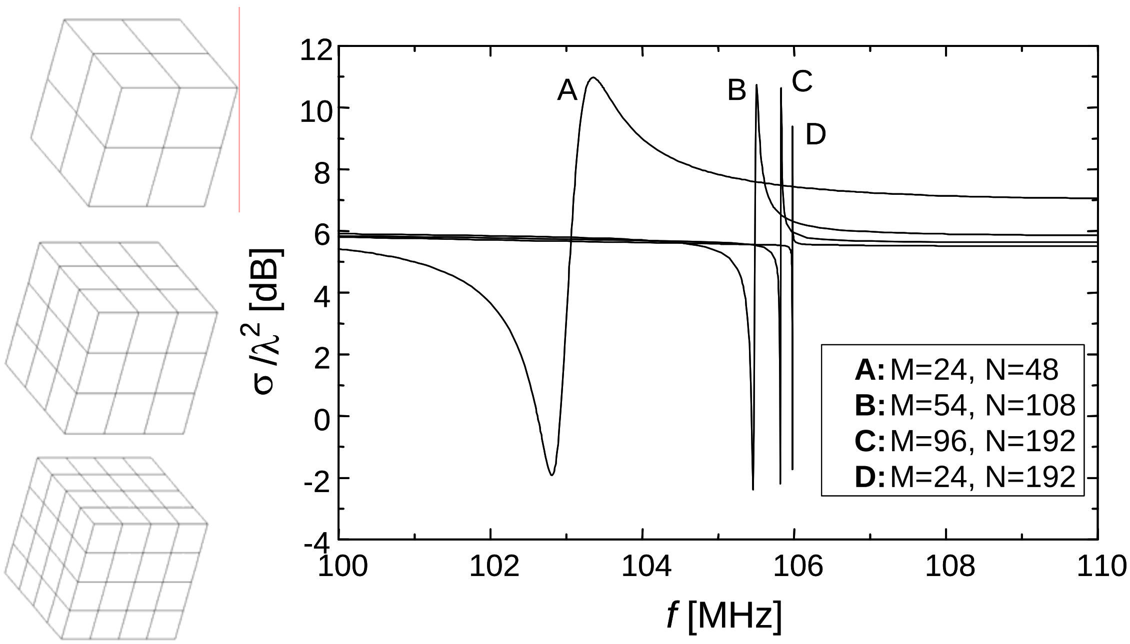
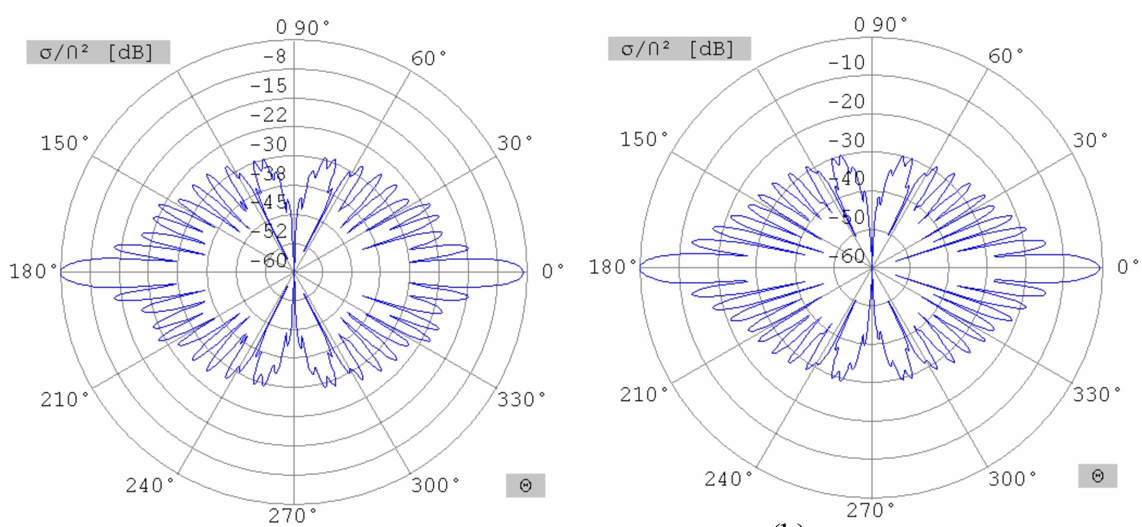


Figure 2. Monostatic RCS of a cubical scatterer of side 2 m in the frequency range near the first internal resonance. In this case, M = the number of patches and N = the number of unknowns. Case D uses WIPL-D with higher order basis functions, yet the number of patches is the same as that of Case A.

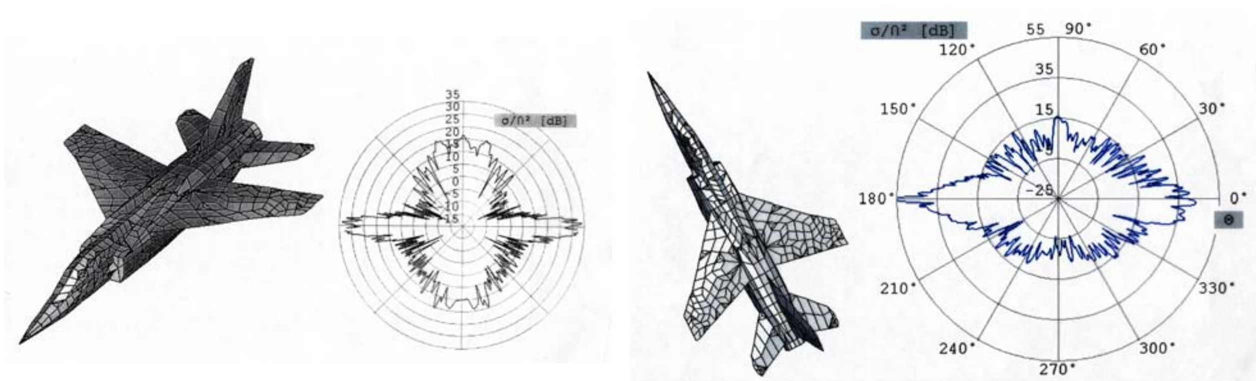
The rapid convergence of WIPL-D as a function of the number of unknowns is illustrated by Figure 3 which shows the bistatic RCS of a cube of side 10λ. The left figure shows RCS obtained by using 1728 unknowns, or 11 unknowns per wavelength squared. The right side shows the same computation using 3072 unknowns, or 20 unknowns per wavelength squared. The two figures are essentially identical. This significant advantage in the economy of unknowns also carries over to long wires, where WIPL-D uses only 3 – 4 unknowns per wavelength. For electrically large metallic surfaces, WIPL-D generally uses 10 – 20 unknowns per square wavelength.

Using higher order basis functions, the time required for WIPL-D computations generally scales as the cube of the ratio of frequencies because the matrix inversion operation scales in this way. Even then it may scale better than some of the other well publicized algorithms like the fast multipole method. This property is illustrated in Figure 4 which shows the RCS of a Mirage fighter aircraft calculated by WIPL-D at 600 MHz and 1 GHz. The incident field is perpendicular to the roll axis of the airplane. The number of unknowns used in these computations was 7760 and 9498, respectively. Therefore the work in WIPL-D scales as $(9498/7760)^3 = 1.83$ since most of the computations involved are in the solution of a matrix equation which typically scales cubically as the number of unknowns. In contrast a fast multipole algorithm for matrix inversion scales as the ratio of the frequencies squared since the number of unknowns per side of a patch increases linearly with frequency. Hence in a fast multipole method the work would scale as $(1/0.6)^2 = 2.78$. This clearly indicates that the use of higher order basis may scale better than a fast multipole method for solution of large scale problems without having to separate the problem into different regions and making some approximations in the computation of the impedance matrix.



(a) (b)

Figure 3. Bistatic RCS of a cube of side 10 λ obtained by using (a) 11 unknowns per wavelength squared and (b) 20 unknowns per wavelength squared. The patterns are virtually identical.



(a) (b)

Figure 4. RCS of a Mirage fighter aircraft (a) calculated at 600 MHz using 7760 unknowns. The normalized RCS of the same target calculated at 1 GHz is shown in (b) calculated using 9498 unknowns.

The most important criterion for choosing an electromagnetic computation program, with the exception of accuracy, is speed of operation. WIPL-D has been demonstrated to be faster than other such programs in addition to its accuracy, discussed earlier in this paper. As an example of the speed of WIPL-D, consider electromagnetic scattering from a cube of side two wavelengths. Using triangular patch basis functions, one would need 225 unknowns per square wavelength. Multiplying by the 6 sides, two components of current, and the factor of four square wavelengths, the number of unknowns required is equal to 10,800. Calculation of the scattering from this cube would require about 100 minutes on a 1 GHz Pentium computer with 512 MBytes of RAM. With the higher order basis functions used in WIPL-D, the same computation will take 14 seconds as the number of unknowns in this case are 972, which is significantly lower in this case .

3. Conclusions

In this paper we have shown that WIPL-D is faster and more accurate than comparable electromagnetic computation programs. These improvements in speed and accuracy result from the method by which basis functions are chosen by the WIPL-D algorithms. Long wires or larger extents of flat plates are modeled using lower order basis functions, while higher order basis functions are used to account for end effects, joints, and curved surfaces. This approach is contrasted with the choice of higher order basis functions for all elements in making electromagnetic computations by other methods. This choice of basis functions is transparent to the user; it is inherent in the WIPL-D software. This approach to basis function determination can be characterized as knowledge-based since the algorithm examines the features of the patch and calculates the basis functions automatically.

Although WIPL-D has been demonstrated to be faster and more accurate than comparable programs, most problems of practical interest still require unacceptably large amounts of time on individual computers, even though these computers may be very fast. To take full advantage of the speed of WIPL-D in solving problems of practical interest, it must be implemented on massively parallel computers.

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